

5 **TRANSMITTER HAVING PROGRAMMABLE TRANSMISSION PARAMETERS**
 TEMPORALLY ALIGNED WITH PAYLOAD AND METHOD THEREFOR

Technical Field of the Invention

10 The present invention relates generally to the
 field of electronic communications. More specifically,
 the present invention relates to a transmitter in which
 transmission parameters are mingled with a payload
 signal to insure that the payload signal is converted
15 into a communication signal configured in accordance
 with the transmission parameters at the proper time.

Background of the Invention

20 In order for communications to be successful, a
 receiver should be mated to a transmitter. In other
 words, both transmitter and receiver should be
 compatible with a common communication protocol. A
 communication protocol sets forth the rules governing
25 the electrical, optical, magnetic, timing, coding, and
 other conventions used for transmitted and received
 signals. Over the years, a vast number of
 communication protocols have been developed, and new
 communication protocols are being developed routinely.
30 Traditionally, communication hardware was designed to
 accommodate a specific communication protocol or small
 range of communication protocols. Accordingly, unless
 special precautions were taken to insure that two
 communication devices, such as radios, shared a common
35 communication protocol, they may very well have been
 unable to communicate.

 A software-defined radio may be able to use one set
 of hardware to engage in communications in accordance

5 with a large number of different communication
protocols. Each communication protocol is implemented
as a result of computer programming which instructs the
one set of hardware how to implement the communication
protocol. If a different communication protocol is
10 desired, then a new computer program or at least
different parameters may be loaded, and the same set of
hardware can successfully communicate in accordance
with the different communication protocol.

A goal of a software-defined radio design is to
15 make the software which defines the communication
protocols as independent of the hardware as possible.
Greater independence is achieved when the software
needs to account for fewer hardware constraints and
needs to directly control fewer aspects of the
20 hardware. With greater software independence comes
greater portability of the software to new, updated,
and different hardware platforms provided by different
manufacturers. In addition, the more independent the
software is from the hardware, the easier and faster
25 the software is to develop and test.

Timing is an aspect of communication protocols
where software has been particularly dependent upon
hardware. In various communication protocols,
including time division multiple access (TDMA),
30 frequency hopping, and others, timing is a significant
attribute. For timing to be precise, as required for
such communication protocols, the software which
implements such communication protocols has
conventionally been required to directly control the
35 specific hardware on which it is running.
Consequently, such software has been difficult and
costly to port to other platforms. Such software has
also been intolerant of changes in the hardware or in

- 5 the software directed to non-timing related functions of the protocol, and has been difficult and costly to develop and test.

10 In a software-defined communication device having an ability to engage in several communication sessions simultaneously, with different sessions using different communication protocols, the direct interface to the communication media, e.g., the air interface for a radio frequency (RF) communication device, is desirably physically separated from and controlled independently
15 from the other signal processing that couples to this direct interface. This architecture permits greater flexibility in applying resources to particular communication session needs and leads to greater reliability. Unfortunately, the benefits this
20 architecture provides are countered by an exacerbated software-controlled timing problem.

Accordingly, what is needed is an architecture that accommodates synchronizing various features of a software-defined communication device while promoting
25 software independence from the hardware.

5

Brief Description of the Drawings

A more complete understanding of the present invention may be derived by referring to the detailed description and claims when considered in connection with the Figures, wherein like reference numbers refer to similar items throughout the Figures, and:

FIG. 1 shows a block diagram of a communication system in which a software-defined radio operates in accordance with one preferred embodiment of the present invention;

FIG. 2 shows a block diagram of the software-defined radio shown in FIG. 1;

FIG. 3 shows an exemplary block diagram of an upstream module of the software-defined radio shown in FIG. 1;

FIG. 4 shows a data format diagram depicting the extraction of programmable transmission parameters from a compound signal in the downstream module in accordance with one preferred embodiment of the present invention;

FIG. 5 shows a data format diagram depicting the extraction of programmable transmission parameters from a compound signal in the downstream module in accordance with another preferred embodiment of the present invention; and

FIG. 6 shows an exemplary block diagram of a downstream module of the software-defined radio shown in FIG. 1.

5

Detailed Description of the Drawings

FIG. 1 shows a block diagram of a communication system 10 in which a software-defined radio 12 operates in accordance with one preferred embodiment of the present invention. Software-defined radio 12 communicates using any number of communication protocols 14 with any number of mate radios 16. A communication protocol may also be called a communication standard or a waveform. A communication protocol sets forth the rules governing the electrical, optical, magnetic, timing, coding, and other conventions used for transmitting and receiving communication signals 18. Mate radios 16 are compatible with the communication protocols 14 supported by software-defined radio 12. In the preferred embodiment, any number of communication protocols 14 may be simultaneously supported by software-defined radio 12, and software-defined radio 12 may be reprogrammed as needed so that different communication protocols 14 are supported at different times.

FIG. 1 depicts communication protocols 14 as applying to communication signals 18 which are bidirectional. However, bidirectional communication signals are not a requirement. The below-presented discussion focuses on a forward link communication signal 18 transmitted from a transmitter in software-defined radio 12 and received at one or more receivers in mate radios 16. Those skilled in the art will appreciate that the teaching of the below-presented discussion can, but need not, be adapted to a reverse link communication signal 18.

5 Likewise, in the preferred embodiment depicted in
FIG. 1, communication protocols 14 apply to radio
frequency (RF) wireless, broadcast communication
signals 18. While communication devices which exchange
this form of communication signals 18 can well benefit
10 from the teaching of the present invention, nothing
prevents the teaching of the present invention from
being used in connection with communication signals 18
transmitted over cables, whether as electrical or
optical signals.

15 FIG. 2 shows a block diagram of software-defined
radio 12. Software-defined radio 12 includes a
transmitter 20 and an optional receiver subsystem 22,
shown in phantom. Transmitter 20 and receiver sub-
system 22 may, but are not required to, share a common
20 antenna sub-system 24.

Input signal sources 26 provide input signals 28 to
any number of software programmable upstream modules 30
of transmitter 20. For compatibility with the
depiction of software-defined radio 12 in FIG. 2 and in
25 subsequent figures herein, reference numbers directed
to lines which connect to blocks, such as reference
numbers 28, are used to indicate the signals which
propagate as indicated by the lines. Input signals 28
convey the payload information to be communicated from
30 transmitter 20.

Each upstream module 30 couples to an input of an
intra-transmitter signal transporter 32, and outputs of
intra-transmitter signal transporter 32 couple to
inputs of any number of software programmable
35 downstream modules 34. Upstream and downstream modules
30 and 34 are so named to distinguish them from each
other and for compatibility with the transmission
direction of signal flow. Those skilled in the art

5 will appreciate that no functional limitation is
implied by these names. While upstream modules 30 and
downstream modules 34 are discussed in detail below,
upstream modules 30 may generally be viewed as
generating their own compound signals 36. Intra-
10 transmitter signal transporter 32 transports compound
signals 36 to various downstream modules 34, where they
are converted into communication signals 18, which are
wirelessly broadcast from transmitter 20 at antenna
sub-system 24.

15 Receiver sub-system 22 and each upstream module 30
couple to a communication protocol library 38 which
stores computer software defining any number of
modulation function sets 40. Each modulation function
set 40 desirably defines a substantially complete
20 communication protocol 14 (FIG. 1). The definitions
may be in the form of computer programming
instructions, variables, lists, tables, and the like.
Through a host controller 42, upstream modules 30 are
in data communication with downstream modules 34.
25 Accordingly, the definitions of modulation function
sets 40 may be provided to both upstream and downstream
modules 30 and 34 as necessary.

In the preferred embodiment, intra-transmitter
signal transporter 32 is a bus operated in accordance
30 with a predetermined bus protocol, such as PCI, VME and
the like. Thus, the benefits of reliability,
simplicity, and low cost associated with the use of a
bus to transport numerous signals to and from numerous
locations are achieved. However, compound signals 36
35 experience varying delays in being transported between
downstream modules 34 and upstream modules 30. The
delays result, at least in part, by requiring compound
signals 36 to experience difficult-to-predict wait

5 states when the bus is occupied transporting other
signals. In an alternate embodiment, intra-transmitter
signal transporter 32 is configured as a switch which
need not impose varying amounts of delay on compound
signals 36 but which may not lead to the benefits of
10 using a bus.

The use of a number of upstream modules 30 and a
number of downstream modules 34 promotes flexibility in
configuring transmitter 20 and promotes reliability of
software-defined radio 12. Nothing requires all
15 upstream modules 30 to have the same hardware
configuration or all downstream modules 34 to have the
same hardware configuration. Desirably, each upstream
module 30 is replaceable independently from the other
upstream modules 30 and from each downstream module 34.
20 Each downstream module 34 is desirably replaceable
independently from the other downstream modules 34 and
from each upstream module 30. Transmitter 20 may be
configured so that any upstream module 30 can feed its
compound signal 36 to any downstream module 34. If a
25 failure occurs in either an upstream module 30 or a
downstream module 34, then the failed module 30 or 34
may be replaced without taking another module 30 or 34
out of service.

FIG. 3 shows an exemplary block diagram of upstream
30 module 30. Desirably, each upstream module 30 has a
hardware configuration similar to the others. In the
exemplary embodiment, upstream module 30 includes a
digital signal processor (DSP) or a collection of DSPs
which are programmed to implement a digital
35 communication modulator 44. The programming which
causes the DSP(s) to implement digital communication
modulator 44 is defined by one of modulation function
sets 40 (FIG. 2). Digital communication modulator 44

5 receives input signal 28 in the form of a digital data stream conveying payload information from signal source 26.

10 Digital communication modulator 44 includes a collection of functions. The collections may differ from one modulation function set 40 (FIG. 2) to another modulation function set 40, and the manner in which each given function may be implemented may differ from function set 40 to function set 40. FIG. 3 depicts a typical collection of functions, but other digital
15 communication modulators 44 may omit some of the depicted functions or include other functions. For example, input signal 28 may be acted upon by a forward error correction (FEC) encode function 46. FEC encode function 46 may implement block, convolutional, turbo,
20 or other encoding schemes known to those skilled in the art in a manner defined by the operative modulation function set 40. Different forms of encoding will impart different amounts of transport delay on the input signal.

25 The encoded input data stream may then be acted upon by an interleave function 48, which imposes additional delay on the payload information. The amount of delay imposed is often determined in response to the type of encoding applied in FEC encode function
30 46. The interleaved signal may then be subjected to a puncture function 50, which slightly alters the timing of the payload information to achieve a specified coding rate.

35 A phase constellation map function 52 phase-maps the input data stream to a complex phase space in accordance with a phase constellation 54 specified by the operative modulation function set 40. FIG. 3 illustrates a QPSK phase constellation 54' and a 16-QAM

5 phase constellation 54", both of which are well
understood by those skilled in the art. Typically, one
modulation function set 40 would define one phase
constellation 54 while another modulation function set
40 would define a second phase constellation 54. Those
10 skilled in the art will appreciate that any number of
different phase constellations may be implemented as
defined by various modulation function sets 40.

The phase mapped input data stream may then be
acted upon by a pulse shape filter function 56, which
15 typically implements a Nyquist, root-Nyquist, raised
cosine, or similar type of filter for purposes of
spectral containment. Different implementations of
phase constellations 54 and pulse shape filter
functions 56 specified by different modulation function
20 sets 40 may impose different amounts of transport delay
on input data stream 28.

Consequently, a processed signal 58 generated by
digital communication modulator 44 at an output of
pulse shape filter function 56 may experience a
25 considerable transport delay which will vary widely
from modulation function set 40 to modulation function
set 40. Moreover, different modulation function sets
40 can be simultaneously implemented in different
upstream modules 30, and upstream modules 30 are
30 reprogrammed from time to time to implement different
modulation function sets 40. Thus, different digital
communication modulators 44 will impart different
transport delays to input signals 28.

The operative modulation function set 40 defining a
35 given communication protocol 14 (FIG. 1) may specify
other characteristics which are affected by timing. In
particular, parameters of the given communication
protocol 14 may affect the RF interface and be applied

5 by a downstream module 34 (FIG. 2) of transmitter 20
(FIG. 2). For example, in a TDMA communication
protocol 14, a power amplifier may need to be keyed off
and on in accordance with strict timing requirements in
order to implement the communication protocol 14. In a
10 frequency hopping application, a carrier frequency of
communication signal 18 (FIG. 1) may need to be
switched to new frequency values in accordance with
strict timing requirements in order to implement the
communication protocol 14. In other applications, baud
15 rates may change from time-to-time in accordance with a
strict schedule, transmit and receive switching may
toggle in accordance with a strict schedule, bandwidths
of filters may need to change in accordance with a
strict schedule, and the like. Such parameters
20 implemented in downstream module 34 are referred to as
programmable transmission parameters 60 herein. In the
preferred embodiment, digital communication modulator
44 mingles programmable transmission parameters 60 with
processed signal 58 to form compound signal 36.
25 Programmable transmission parameters 60 may be mingled
with processed signal 58 in a multiplexer (MUX) 62 or
other function as best suited to a particular
application.

FIG. 4 shows a data format diagram depicting the
30 mingling of programmable transmission parameters 60
with processed signal 58 to form compound signal 36 in
accordance with an "in-parallel" embodiment of the
present invention. As depicted in FIG. 4, each sample
64 of processed signal 58 is accompanied in-parallel by
35 control bits 66 that convey programmable transmission
parameters 60. For example, fourteen bits of each word
from a stream of sixteen bit words may convey samples
from processed signal 58 while the remaining two bits

5 of the sixteen bit words in the data stream convey
control bits 66. In this example, one of the two
control bits may indicate when to key an RF power
amplifier and another of the two control bits may
10 indicate when to switch to a different carrier
frequency.

FIG. 5 shows a data format diagram depicting the
mingling of programmable transmission parameters 60
with processed signal 58 to form compound signal 36 in
accordance with an "in-series" embodiment of the
15 present invention. As depicted in FIG. 5, sample
blocks 64' of processed signal 58 may be interspersed
in-series with blocks 66' of control data. Control
data blocks 66' may be of any desired length, and that
length may vary as needed to convey a needed amount of
20 data. Desirably, control data blocks 66' include data
which indicate relative timing for when the control
data should take effect. For example, the control data
may be configured to take effect immediately following
the control data block 66' in which it is evaluated.

25 Referring back to FIG. 3, compound signal 36 output
from mingling function 62 serves as an output from
digital communication modulator 44. Compound signal 36
is routed to a first-in, first-out (FIFO) memory buffer
68 which imposes varying amounts of delay on compound
30 signal 36. However, any delay imposed on processed
signal 58 is likewise imposed on programmable
transmission parameters 60. Thus, programmable
transmission parameters 60 remain synchronized with
processed signal 58. After experiencing delay in FIFO
35 memory buffer 68, compound signal 36 is routed through
a bus interface 70 and connector 72, where it is passed
to intra-transmitter signal transporter 32 (FIG. 2).

5 Connector 72 promotes the independence of upstream
modules 30 from downstream modules 34 within
transmitter 20 by allowing upstream modules 30 to be
independently replaceable from downstream modules 34.
Bus interface 70 determines when intra-transmitter
10 signal transporter 32 is available for transporting
samples of compound signal 36, and obtains such samples
from FIFO memory buffer 68 when appropriate. FIFO
memory buffer 68 allows digital communication modulator
44 to operate at a constant clock speed in spite of
15 compound signal 36 samples being transported on intra-
transmitter signal transporter 32 at a non-constant
rate.

FIG. 6 shows an exemplary block diagram of a
downstream module 34 of transmitter 20 (FIG. 2).
20 Compound signal 36 passes from intra-transmitter signal
transporter 32 (FIG. 2) through a connector 74, a bus
interface 76, and into a FIFO memory buffer 78.
Connector 74 promotes independence of upstream modules
30 from downstream modules 34, bus interface 76
25 provides address decoding and control functions for
intra-transmitter signal transporter 32. FIFO memory
buffer 78 imparts varying amounts of delay on compound
signal 36 to synchronize compound signal 36 to a time
base established by a clock circuit 80 for downstream
30 module 34.

A demultiplexer (DEMUX) 82 obtains compound signal
36 from FIFO memory buffer 78 in synchronism with a
clock signal 84 generated by clock circuit 80 and
extracts programmable transmission parameters 60 from
35 compound signal 36 to recover processed signal 58. The
extraction process performed by demultiplexer 82 is
illustrated in FIGs. 4 and 5 for the in-parallel and
in-series embodiments discussed above. Extracted

5 programmable transmission parameters 60 are supplied to
a transmission parameter applicator 86, and recovered
processed signal 58 is supplied to a digital-to-analog
converter (D/A) 88. Digital-to-analog converter 88
converts the digital form of processed signal 58 into
10 an analog form 58' of processed signal 58 in response
to clock signal 84. Specifically, an output of
digital-to-analog converter 88 couples to a first input
of an upconverter 90. Upconverter 90 converts
processed signal 58' into communication signal 18. An
15 output of upconverter 90 couples to an input of an RF
power amplifier (P.A.) 92, and an output of RF power
amplifier 92 couples to an antenna 24' from antenna
sub-system 24 (FIG. 2). Communication signal 18 is
wirelessly broadcast from transmitter 20 at antenna
20 24'.

Transmission parameter applicator 86 has outputs
corresponding to the various programmable transmission
parameters 60 which are applied in downstream module
34. One output of transmission parameter applicator 86
25 couples to a control input of a synthesizer 94 to
specify the frequency of a signal generated by
synthesizer 94. A clock input of synthesizer 94
couples to an output of clock circuit 80, and an output
of synthesizer 94 couples to a second input of
30 upconverter 90. Thus, the frequency of the signal
generated by synthesizer 94 corresponds to the carrier
frequency of the communication signal 18 generated by
downstream module 34.

Another output of transmission parameter applicator
35 86 couples to a control input of RF power amplifier 92.
Keying of RF Power amplifier 92 may be provided through
this control input. Another output of transmission
parameter applicator 86 couples to clock circuit 80 and

5 may be used to establish the clock rate for digital-to-analog converter 88 and a baud rate for the communication signal 18 generated by downstream module 34. As indicated at an output 96 from transmission parameter applicator 86, other programmable
10 transmission parameters may be provided to control filter bandwidths, control transmit/receive timing, and the like.

Accordingly, carrier frequencies, keying, and other attributes of communication signal 18 are configured in
15 accordance with programmable transmission parameters 60. The timing at which programmable transmission parameters 60 are mingled with processed signal 58 in upstream module 30 defines the timing at which such programmable transmission parameters 60 take effect in
20 communication signal 18, produced by downstream module 34.

In summary, the present invention provides an improved transmitter having programmable transmission parameters temporally aligned with payload data and an
25 improved method therefor. Software independence from hardware is accommodated while synchronizing various features of a software-defined communication device. Software independence is accommodated because the variable timing associated with implementing different
30 modulation function sets 40 in upstream modules 30 and the variable timing associated with transporting processed signals 58 over intra-transmitter signal transporter 32 need not be considered and tracked by the software. Programmable transmission parameters are
35 applied synchronously to payload data even though different instances of payload data experience varying amounts of delay caused by any number of factors.

[illegible]